Determination of Additional Effective Dose and Radiological Risk Assessment for Exposed Population

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The paper represents a study of radioactive pollution in uraniferous exploitation mining area. Based on activity concentrations measurements of radionuclides as U, Ra, Th and Rn in surface water, soil and air, and also γ dose rate at external irradiation, the annual supplement effective dose values were calculated, and from these, were obtained the radiological risc coefficients for population. The measurements were made in polluted areas where exist exploitation mining activities and also in distant areas with population. By the results obtained, were made some recommendations [1-3] regarding the protection of exposed population.

Keywords: radiological risk, dose, exposure, radioactive pollution, ingestion, inhalation

At present, there are many radioactive polluted areas as a result of some mining exploitation activities, being now totally or partially deallocated. The population who lives in the proximity of these areas are exposed to radiological risk due to the radioactive pollution existed in those areas. External irradiation is due to radiation and both irradiations (external and internal) are analysed in terms of 3 exposure pathways: terrestrial, aquatic and aerial.

For a quantitative assessment of the radiological risk, there was adopted a classification system in which both the probability that the event to meet its target and the action magnitude on the receptor are classified according to an arbitrary score [4].

a) The probability that the action of radiation to reach its target so that to cause measurable damages, is classified as follows:

- high, coefficient 4;
- medium, coefficient 3;
- slight, coefficient 2;
- low, coefficient 1.

b)The magnitude of damages is analogously classified:

-very high, coefficient 5: additional annual effective dose over 5 mSv/year;

- high, coefficient 4: additional annual effective dose around 5 mSv/year;
- moderate, coefficient 3: additional annual effective dose around 3 mSv/year;
- low, coefficient 2: additional annual effective dose around 2 mSv/year;
- negligible, coefficient 1: additional annual effective dose 1 mSv/year or less.

Thus, there was obtained a matrix of determining radiological risk to the population in the uranium mining area, the risk being defined as the product between probability and magnitude.

Radiological risk = Probability x Magnitude

This matrix presented in table 1, quantitatively assesses the radiological risk based on risk factor values, comprised between 1 and 20. On this basis there can be established a scale of radiological risks for the population in uranium mining area.

Risk factor values are determinated by the value of the additional annual effective dose received by population, a dose which in turn is determined by the activity concentration of radionuclides existing in the polluted environment from the evaluated area. Consequently, these activity concentrations for the radionuclides of interest elements: U, Ra, Th, Rn + short-lived daughters have been experimentally determined. Then, there were calculated the additional annual effective doses received by one person in the population in various ways: land, aquatic and aerial areas.

Table 1
MATRIX FOR DETERMINING RADIOLOGICAL RISK COEFFICIENT FOR PEOPLE IN URANIFEROUS MINING INDUSTRY

Probability of radionuclides to get, through different ways, to human receptor	Value of additional annual effective dose (mSv/an) received by a person in the irradiated population (magnitudine)				
	Very high over 5 mSv/year	High 4 mSv/year	Moderate 3 mSv/year	Low 2 mSv/year	Negligible 1 mSv/year
High (coefficient 4)	20	16	12	8	4
Medium (coefficient 3)	15	12	9	6	3
Slight (coefficient 2)	10	8	6	4	2
Low (coefficient 1)	5	4	3	2	1

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Experimental part

The activity concentration for radionuclides of interest elements (U, Ra, Rn + short-lived daughters) was determined by direct measurements in site or by taking samples analysed in laboratory (over 500 samples and measurements).

External radiation assessment, i.e. the measurement of the dose rate due to γ radiation it was carried directly out on the ground at 1m from the surface, using a radiometer type Eberline FH-40-F2 (Germany) with a sensitivity of 0.02 μSv / h and an uncertainty of 6% for a confidence level of P = 99.73%.

For determining the activity concentration of U, Ra and Th in soil samples (sediments material in the pond), there were collected samples using a sonde specifically designed to be sample from different depths. The samples were then analyzed in the laboratory. Uranium was spectrophotometrically dosed in the presence of ARSENAZO III [5], while Ra, Th and K were calculated by γ spectrometry using a multichannel analyzer with hyper pure Ge detector as follows [6-10]:

· Radium was dosed following γ lines emitted by ^{214}Pb and ^{214}Bi, after establishing the complete radioactive equilibrium between radium and its progeny (at least 30 days);

· Thorium was dosed following γ lines emitted by ^{228}Ac and ^{208}Tl;

· Potassium was dosed following γ line from 1460 keV emitted by radionuclide ^{40}K.

Field determination of activity concentrations of radon and its daughters in the air was carried out by alpha spectrometry with a RAD-7 electronic detector which has a sensitivity of 4 Bq/m^3 and can measure activity concentrations of ^{222}Rn and ^{220}Rn in the (4-400000) Bq/m^3 domain. The radon flux was measured with the same electronic detector, RAD-7, coupled to a special enclosure for the radon accumulation. Activity concentrations of radon in water were also determined with a RAD-7 detector coupled to a special adapter for the determination of radionuclides ^{222}Rn and ^{220}Rn in water samples. Accessible range of activity concentrations in the field measurements in water samples is 1.85 Bq / L - 9250 Bq / L.

Results and disscusions

Lişava mining area is situated at south-west of Caras-Severin city (Romania), on western part of Anina Mountains. This area presented a radiological potential risk for people who live nearest. This paper seeks to assess this risk by determining the effective dose received by people in the area during a year.

The field experimental measurements were made in three different locations inside of three scenarios, presented in figure 1.

Scenario 1 has into consideration a person who lives beside the radioactive source composed by poor ore dump – Dobrei and uranium retrievel station.

Scenario 2 is located at confluence of Natra creek with Lişava creek, in contaminated soil surface wherefrom was evacuated the ore enriched with uranium and at 400 m surety of uranium retrieval station.

Scenario 3 is located in critical group – Brădişorul de Jos locality, at 4.5 km from mining area, group formed by about

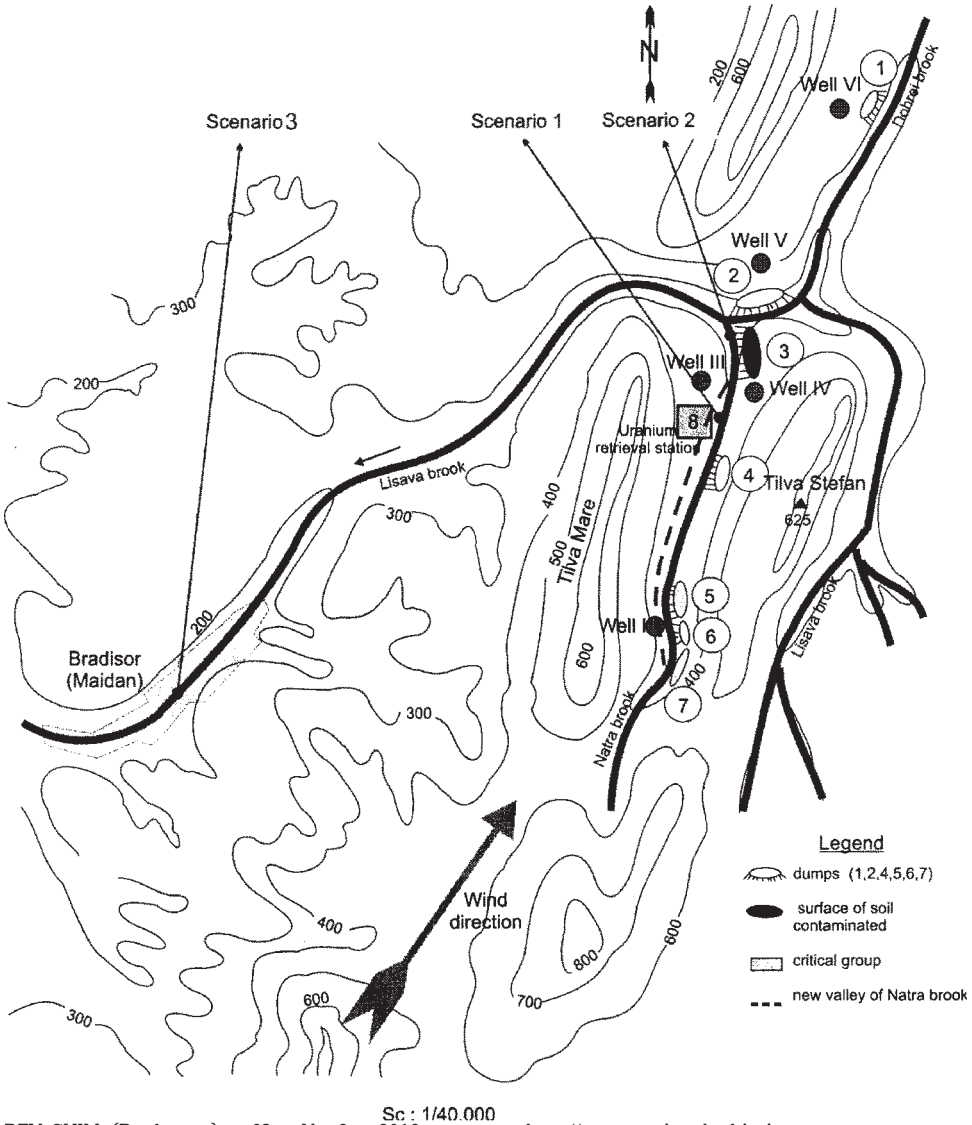

Fig. 1. Scenario localization used for effective dose determination received by population from critical groups

1000 persons, being the first group located downstream of uraniferous mining area.

Present measurements were performed in the field and outside the mine perimeter for establishing the background values for each exposure way (land, water and air) to the radiation action.

The results are summarized in tables 2-6. Each value in these tables represents the arithmetic mean of at least 10 numbers of values obtained by repeated measurements under similar conditions, being made totally over 500 experimental determinations.

Table 2
VALUES OF RADIOACTIVE POLLUTION PARAMETERS OUTSIDE LISAVA URANIUM MINING ZONE (BACKGROUND VALUES)

Parameter	Value measured	
	Lişava mining area	Brădişorul de Jos locality
γ dose rate	0.16 μSv/h	0.09 μSv/h
Rn activity concentration at surface	30 Bq/m^3	15 Bq/m^3
U concentration at Natra and Lişava Creek	0.005 mg/l	0.005 mg/l
Ra activity concentration at Natra and Lişava Creek	0.004 Bq/l	0.004 Bq/l

Table 3
VALUES OF RADIOACTIVE POLLUTION PARAMETERS IN LIŞAVA MINING AREA, CASE OF SCENARIO 1

Parameter	Value measured
γ dose rate at area surface with poor ore	4.25 μSv/h
Rn activity concentration at surface	650 Bq/m^3
U concentration in poor ore from Dobrei dump	0.026 % (mass)
U concentration in mining water which leaves from Well 3 when unpolluted station doesn't works	2.5 mg/l
Ra activity concentration in mining water which leaves from Well 3 when unpolluted station doesn't works	0.35 Bq/l

Table 4
VALUES OF RADIOACTIVE POLLUTION PARAMETERS OF WATERS IN LIŞAVA MINING AREA, CASE OF SCENARIO 1, WHEN UNPOLLUTED STATION WORKS (TOPICAL SITUATION)

Parameter	Value measured
U concentration in mining water after exit the unpolluted station	0.73 mg/l
Ra activity concentration in mining water after exit the unpolluted station	0.22 Bq/l
U concentration in Natra Creek surety of station and, after confluence with waters who exit from unpolluted station	0.180 mg/l and 0.650 mg/l
Ra activity concentration in Natra Creek surety of station and, after confluence with waters who exit from unpolluted station	0.085 Bq/l and 0.190 Bq/l

Table 5
VALUES OF RADIOACTIVE POLLUTION PARAMETERS IN LIŞAVA MINING AREA, CASE OF SCENARIO 2

Parameter	Value measured
γ dose rate at surface whence ore was evacuated (former deposit)	4.26 μSv/h
Rn activity concentration at surface	520 Bq/m^3
U concentration in Natra Creek (minimum debit) when station not working and mining water from Well 3 flowing directly in Natra	2.1 mg/l
Ra activity in Natra water Creek after confluence with mining water from Well 3	0.30 Bq/l
U and Ra concentration in Natra water Creek when station not working and water from station flowing directly in this creek	U: 0.63 mg/l Ra: 0.18 mg/l

Table 6
VALUES OF RADIOACTIVE POLLUTION PARAMETERS IN LIŞAVA MINING AREA, CASE OF SCENARIO 3, LOCATED IN BRĂDIŞORUL DE JOS LOCALITY

Parameter	Value measured
γ dose rate	0.08 μSv/h
Rn activity concentration at surface	15 Bq/m^3
U and Ra content in Lişava water creek (minimum debit) when unpolluted station is not working	U: 1.36 mg/l Ra: 0.19 Bq/l
U and Ra content in Lişava water creek (minimum debit) when unpolluted station is working	U: 0.4 mg/l Ra: 0.12 Bq/l

Based on these values there were subsequently calculated different components of the additional annual effective doses and the additional annual total effective dose from which the respective coefficients of radiological risk for the people in the uranium mining zone investigated, were finally obtained.

Total annual effective dose, E_T, is the sum of all the doses received by a person through the following three ways:

1. *Land way:*

a) Gamma external irradiation leads to the *effective dose* E_g;

b) Internal irradiation by ingestion of contaminated materials (soil, mud, fine dump material, etc.) leads to the *internal effective dose*, E_i^c.

2. *Aquatic way:*

Internal irradiation by direct or indirect water ingestion of vegetal and animal food determines internal *effective dose*, $E_i^a + E_i^b$.

3. *Air way:*

a) Internal irradiation by radioactive dust inhalation determines *internal effective dose*, E_{hi};

b) Internal irradiation by radon and its short-life daughters inhalation leads to *internal effective dose*, E_{hRn}.

With these definitions and notations it comes out that:

$$E_T = E_\gamma + E_i^c + E_i^a + E_i^b + E_{hi} + E_{hRn} \quad (1)$$

Total additional effective dose, $E_{addition}$, is given by the relation:

$$E_{addition.} = E_T - E_{T\ background} \quad (2)$$

In which $E_{background}$ represents the total effective dose determined by the *natural background* of radiations. Its value varies pretty much from a geographical area to another one, the medium value for the entire planet being [11] of 2.4 mSv/year. That means, in concrete cases, to determine the *total annual effective dose*, $E_{T\ background}$, which is given by the *local natural background*. This value, $E_{background}$, is composed from the same components as E_T and, consequently, the background values must be established for all the ways (aquatic, land and air) under the same conditions as when determining E_T.

External effective dose, E_γ, is calculated from debit dose measured in the field, on the basis of the relation [12]:

$$E_\gamma = t \cdot D_\gamma \cdot 10^{-3} \quad mSv/year \quad (3)$$

where: t – exposure time (hours/year) = 7000;

D_γ - value of gamma dose rate measured in the field (μSv/h).

Internal effective dose, E_i^c, due to ingestion of contaminated materials, is given by [12]:

$$E_i^c = C_r \cdot M_{ing} \cdot DC \cdot 10^3 \quad [mSv/year] \quad (4)$$

in which:

M_{ing} – consumption rate = 22 g/year, according to [12];

DC – coefficient of activity – dose conversion [13] (Sv/Bq);

C_r – activity concentration of the ingested (Bq/g) experimentally measured radionuclide

Internal effective dose, E_i^a, due to water ingestion (aquatic way) has the following formula [12]:

$$E_i^a = C_r \cdot I_r \cdot DC \cdot 1000 \quad [mSv/year] \quad (5)$$

In which:

C_r – activity concentration of the radionuclide ingested, experimentally deduced from the present results (Bq/L);

I_r – ingestion rate = 730 l/year, according to [12];

DC – coefficient of activity - dose conversion (Sv/Bq), listed in the tables [13], for each evaluated radionuclide.

Internal effective dose, E_i^b, due to food ingestion by transfer of radionuclides from contaminated water and soil, is also calculated with formula (4) as in the case of E_i^c dose due to ingestion of materials contaminated.

Annual internal effective dose, E_{hi}, due to inhalation of radioactive dust have the formula [13]:

$$E_{hi} = C_r \cdot t \cdot V \cdot DC \cdot 1000 \quad [mSv/year] \quad (6)$$

in which:

C_r – activity concentration of radionuclide in source (Bq/m^3);

t – exposure time = 7000 h/year, according to [12];

V – volume of air inhaled per hour = 0.93 m^3/h, according to [12];

DC – coeficient of activity – dose conversion (Sv/Bq), presented in the table for each radionuclide.

Annual effective dose, $E_{h\ Rn}$, due to inhalation of radon and its short-lived daughters, is expressed as:

$$E_{h\,Rn} = C_{Rn} \cdot t_{exp} \cdot r \cdot C_{ech} \cdot DC \quad [mSv/year] \quad (7)$$

where:

C_{Rn} – activity concentration of radon in air (Bq/m^3)

t_{exp} – exposure time = 7000 h/year, according to [12]

DC – coefficient of activity – dose conversion [mSv/Bq], for public = 6.3 . 10^{-6} Sv/Bq 13]

C_{ech} – equilibrium coefficient between radon and its short-lived daughters = 0.4 for exterior and also in interior, according to WISMUT-PHARE PROJECT [14].

Starting from these relatioships (1-7) and the experimental values listed in tables (1-6), the total annual effective doses values and the additional ones in the case of three scenarios under consideration were calculated. The values are presented in table 7. For these determinations, it was considered real situation from those scenarios in which will obtain the higher total effective dose. Thus, to calculate the effective dose due to water and food product ingestion is considered the variant in which debits of Natra and Lisava creek have minimum values and uranium retrieval station working at topical real parameters.

The data presented in table 7 show that the total dose obtained by summing all the doses received through of all the 3 ways (terestrial, aquatic and aerial), are higher and same value in scenario 1 and 2, but in scenario 3, this dose is net different, being much smaller, with almost size grade. Thus, in case of scenario 1 (the person lives beside radioactive source composed by poor ore dump – Dobrei and uranium retrieval station), additional annual effective dose has about 4.2 mSv/year, being much higher than 1 mSv/year value, considered by Romanian legislation [13] being maximum admitted limit. According to the data presented in table 1, the value of the radiological risk factor will be 4x4=16, if the person will live permanently in this area (higher probability with coefficient 4), which means a major radiological risk.

Table 7

ANNUAL ADDITIONAL EFFECTIVE DOSE RECEIVED BY A PERSON IN POPULATION, ON DIFFERENT WAYS, IN CASE OF THE ENTIRE 3 SCENARIO

Way	Dose element	Scenario 1 (mSv/an)			Scenario 2 (mSv/an)			Scenario 3 (mSv/an)		
		Total	Back-ground	Additional	Total	Back-ground	Additional	Total	Back-ground	Additional
Terestrial	E_γ	3.440	1.340	2.100 (50.0%)	3.44	1.34	2.10 (54.0%)	0.700	0.700	Negligible
	E_i^c	0.001	-	Negligible	0.001	-	Negligible	UDL*	-	Negligible
Aquatic	E_i^a	0.961	0.007	0.954 (22.7%)	0.883	0.007	0.876 (22.5%)	0.564	0.007	0.557 (83.1%)
	E_i^b	0.299	0.004	0.295 (7.1%)	0.219	0.003	0.216 (5.5%)	0.116	0.003	0.113 (16.9%)
Aerial	E_{hi}	0.002	-	Negligible	0.001	-	Negligible	UDL*	-	Negligible
	E_{hRn}	1.380	0.530	0.850 (20.2%)	1.230	0.530	0.700 (18.0%)	0.260	0.260	Negligible
Total	E_T	6.083	1.881	4.199	577.4	1.881	3.892	1.64	0.970	0.670

*UDL – under detection limit

In case of scenario 2 (person will lives permanent nearest at confluence between Natra and Lisava Creek, in contaminated soil surface whence the uranium enriched ore was evacuated and at 400 m dawnstream of uranium retrieval station), the additional annual effective dose, according to table 7 is almost 3.9 mSv/year, leading, also in this case to a radiological risk coefficient equal to 16, meaning also a major radiological risk.

In case of scenario 3, located in critical group Brădişorul de Jos locality, situated at 4.5 km of radioactive area, the total annual effective dose is only 0.67 mSv/year, under 1 mSv/year limit, considered as maximum admitted for population. This means risk coefficient 4, low radiological risk.

Regarding the component of additional effective annual dose, in scenario 1 and 2, terrestrial component (external γ irradiation) is predominant, about 50%, followed by aquatic component ($\approx$ 30%) and aerial component (radon inhalation and short lived descendents), which represent about 20%. In scenario 3, the aquatic component represents 100%, the other components (terrestrial and aerial) being negligible.

Conclusions

In this paper are presented the results of an experimental study of radioactive pollution in Lişava uraniferous mining exploitation. Based on activity concentration determination for radionuclides of interest element: U, Ra, Th and + short live descendent, and from γ flow dose measurements, are calculated the additional effective annual doses received by population in different ways: terrestrial, aquatic and aerial, in case of 3 different scenario had in view, in which the person will live in different location in raport with radiation source from mining area. From these additional effective annual doses are calculated then the radiological risks coefficients for population in those location. In scenario 1 and 2 (in vicinity of radiation source), exist a major radiological risk, so these areas cannot be inhabitated, while in scenario 3, at 4.5 km by radiation source, in Brădişorul de Jos locality, with about 1000 peopls, the additional annual effective dose has values under 1 mSv/year limit, admitted by working legislation, which means an insignificant radiological risk for population from this area.

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Manuscript received: 16.05.2011